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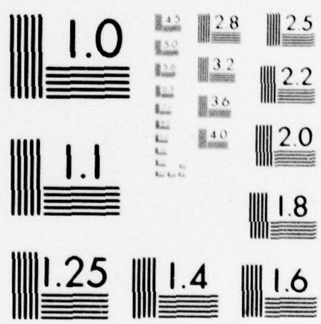

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*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

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Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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Table of Contents

2371

EFFECT OF COMPLEX ALLOYING ON THE PROPERTIES AND STRUCTURE OF α-ALLOYS

V. P. Kurayeva, O. P. Solonina, Zh. D. Tkhorevskaya

Titanium alloys with increased heat resistance have become known in recent years. They are mainly alloys based on an α-structure obtained by hardening the α-solid solution by making its composition more complex and using complex alloying.

There are two trends in the development of these heat-resistant alloys. On one hand, high-alloy alloys with the maximum aluminum content, which prevents the manifestation of the ordered α_2-phase, are being used as their base. On the other hand, complex alloying of alloys containing 2.25-6o/o Al is being realized. Along with aluminum, "neutral hardeners" - tin and zirconium - are being added

to these alloys. Although these elements are less effective alloying elements than aluminum, they have a favorable effect on heat resistance.

Zirconium has a positive effect on this characteristic at high temperatures, forming a large region of α-solid solution with titanium. Tin raises creep resistance and tends to form ordered solutions with α-titanium [1]. A small quantity of β-stabilizing elements prevents embrittlement caused by the transitional phases in alloys containing 8o/o or more Al.

Alloy VT18, developed on the basis of the system Ti-Al-Zr, has higher heat resistance at 550-600°C than the existing titanium alloys and stress-rupture strength of 28-30 kg/mm² at 600°C for 100 hours with satisfactory stability.

The effect of complex alloying on these characteristics was studied in order to raise the thermal stability and heat resistance of alloy VT18. The work was done in two areas: 1) replacing a certain quantity of aluminum or zirconium in the alloy by tin, and 2) additional alloying of the alloy with copper, hafnium and tungsten.

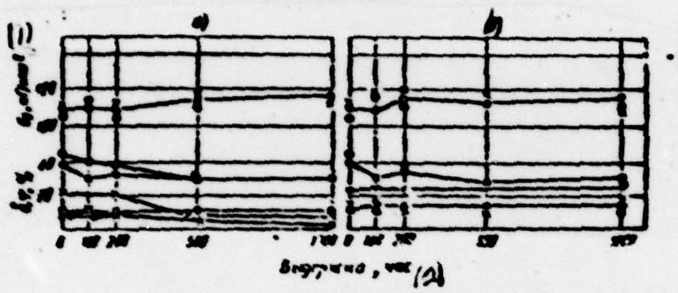
In order to raise the thermal stability of alloy VT18 while preserving its heat-resistant properties at 600°, part of the

aluminum and zirconium was replaced by tin. Alloys containing less than 7o/o Al and 8o/o Zr with a constant quantity of niobium and molybdenum were used for the study. Furthermore, 0.2o/o Si was added to some of the alloys containing 2o/o Sn. The test results showed that additional alloying of alloys with tin does not significantly change their stress-rupture strength and plasticity at room temperature compared to these properties of alloy VT13. Here the impact viscosity increases from 2-3 to 4.5.4 kgm/cm². An increase in the stress-rupture strength from 115 to 120 kgm/cm² and a reduction in impact viscosity from 4.1-5.2 to 1 kgm/cm² are only observed in the alloy with 7.5o/o Al additionally alloyed with 2o/o Sn.

As the tests showed (Fig. 1), after heating alloys which do not contain silicon for an additional 100 hours at 600°, their thermal stability is completely satisfactory: a certain decrease in plasticity and increase in strength are observed. Plasticity decreases more markedly when the tin content is increased from one to 3.5o/o. Thus, in an alloy with 1o/o Sn, $\psi = 30\%$, and with 3.5o/o Sn, $\psi = 24\%$. Similar results on thermal stability were obtained after heating the alloy at 550° for 100 hours. Increasing the duration of heating from 100 to 500-1000 hours at the same temperatures essentially does not change the plastic properties of an alloy with 1-2o/o Sn.

Fig. 1. Mechanical properties of alloy Ti - 7o/o Al - 8o/o Zr - 1o/o Nb - 0.55o/o Mo - Sn with different tin additives at room temperature after holding for 100-1000 hours at 550 (a) and 600° (b):

●-1% Sn; O-3% Sn; X-3.5% Sn. KEY: (1) kg/mm². (2) Holding, h.



Alloys with 0.2o/o Si have lower thermal stability, whereupon the higher their aluminum and zirconium content, the lower their plasticity. Increasing the quantity of tin in the alloy from one to 3.5o/o increases its short-term strength at to 5-10 kg/mm² 500-700° (Fig. 2). The results of long-term tests showed that alloys with 3.5o/o Sn (without silicon) have a high level of heat-resistance characteristics (σ_{100}^{600} = 30—31 kg/mm²). With the addition of 0.2o/o Si to the alloy, as well, its heat resistance increases (σ_{100}^{600} = 33 kg/mm²; σ_{30}^{500} > 74 kg/mm²), but its thermal stability drops.

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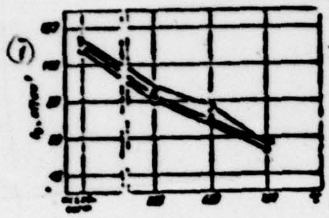
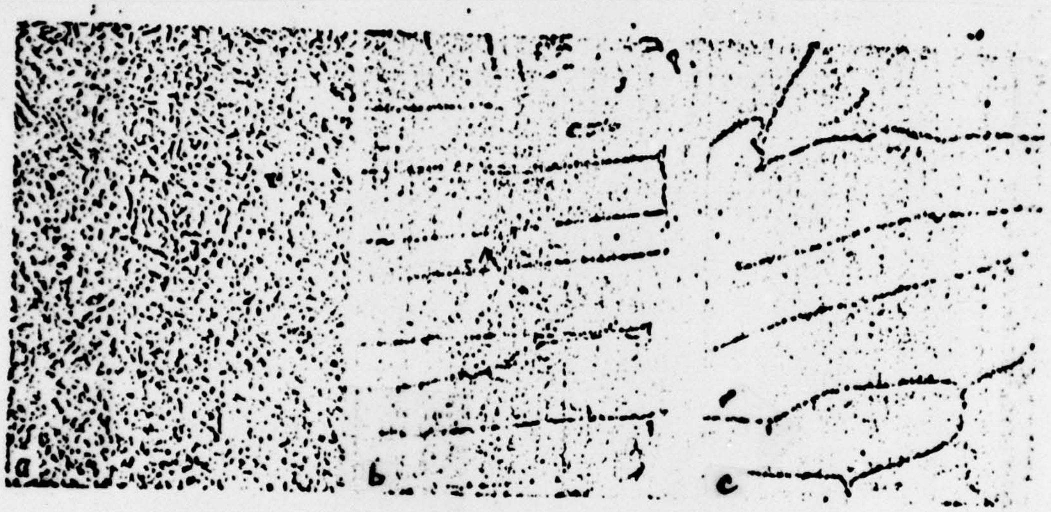
Fig. 2. Short-term strength of alloys type VT18 with iifferent tin contents at raisei temperatures: O–1% Sn; ●–2% Sn; x–3.5% Sn. . KEY: (1) kg/mm².



The study established that the structures of alloys without additives and with tin additives in the annealed state and after additional heating-and-cooling cycles at working temperatures are similar to and resemble the "basketweave" structure. Examination under an optical microscope (x300) shows that the structure of the alloy consists of plates of α-phase with dark inclusions on its boundaries (Fig. 3a), while bands differing from the α-phase (Fig. 3b, c) were observed against the background of the α-solid solution under an electron microscope (x10,000). They become wider as the tin content in the alloy is increased from one to 3o/o (Fig. 3c). These bands can either be considered to be the effect of the chemical heterogeneity on the edges of the α-grains, or they can be explained by the presence of the second phase in the alloy.

Fig. 3. Microstructure of alloy VT18 with different tin additives:

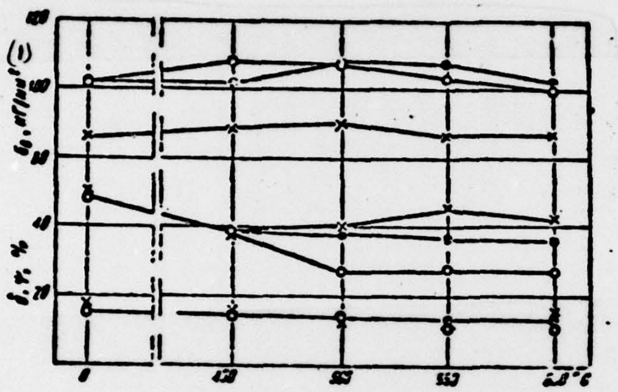


The phase analysis[1] showed that alloy VT18 alloyed additionally with tin obviously consists of two α-phases which differ in their content of aluminum and other alloying elements, as well as the β-phase, whose quantity also varies with the composition of the alloy. Footnote: [1]Work conducted by Ye. I. Gus'kov. End footnote

The content of the α-phase stripped of alloying elements and the β-phase is obviously very small; thus, they do not have a significant effect on the alloy's heat resistance. Its high heat-resistance properties probably result from hardening of the α-solid solution.

As we know, copper increases the creep resistance of titanium alloys, while preserving good thermal stability [2]. 0.8 and 2o/o Cu were added to alloy VT18 for this purpose (Fig. 4). The test results (Fig. 4) showed that the alloy has high thermal stability after 100 additional hours of heating at 450, 500, 550 and 600°; here its relative contraction is 34.3-41.6o/o. The alloy has high creep resistance and reduced stress-rupture strength at 550 and 600°. Its residual deformation at 500° and σ = 35 kg/mm² for 100 hours is 0.08o/o.

Fig. 4. Mechanical properties of alloy type VT18 with additives of copper and hafnium at room temperature after holding for 100 hours at 450, 500, 550 and 600°: ●–0.8% Cu; O–2% Cu; X–6% Hf. KEY: (1) kg/mm².



The addition of 0.8o/o Cu to the alloy does not affect its phase composition and microstructure, but further increasing the copper content to 2o/o reduces its heat-resistance properties. This is obviously due to the manifestation of the β-phase.

Like zirconium, hafnium is a titanium analog. We know that hafnium increases the creep resistance of alloys based on Ti-Al without changing their phase composition [1, 3].

The replacement of 6o/o Zr in the alloy by 6o/o Hf reduced its

strength properties at room temperature and raised temperatures, as well as the heat resistance of the alloy (see Fig. 4). However, its thermal stability remained high after an additional 100 hours of heating at all temperatures. The alloy's structure did not change when zirconium was replaced by hafnium.

Tungsten forms a eutectoid decompositon system with titanium. The maximum solubility of tungsten in α-titanium alloys is less than 0.8o/o, which indicates the low diffusion rate of this element.

We know that the addition of tungsten raises the heat-resistance characteristics of titanium alloys without reducing their plasticity and stability. Thus, the creep limit of alloy VT3-1, which contains tungsten instead of chromium, doubles at 450°C [4]. Alloy VT18 to which tungsten has been added instead of β-stabilizing elements (niobium and molybdenum) has high short-term strength at 550-600° and high creep resistance at 600° and σ = 10 kg/mm² for 100 hours. Here its residual deformation is 0.035o/o. However, this alloy has low thermal stability, which is probably related to the change in its phase composition.

Conclusions

The replacement of part of the aluminum and zirconium in alloy VT18 with tin (2o/o) increases its thermal stability while preserving its high heat-resistance properties.

2. The addition of copper or tungsten to alloy VT18 increases its creep resistance. The content of the indicated additives, as well as aluminum and zirconium, in the alloy must be precisely determined here in order to obtain the optimum set of properties.

3. Tin, copper and hafnium additives do not change the structure and phase composition of the alloy within the limits of the α-solid solution.

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2371a

STRUCTURE AND PROPERTIES OF A HEAT-RESISTANT TITANIUM ALLOY WITH A LONG SERVICE LIFE AT 500-550°

O. P. Solonina, N. M. Ulyakova and M. I. Yermolova

We know that as heat resistance increases in the process [Tr. note: incorrect line inserted here in Russian text; correct line missing] ... alloys have a tendency toward reduced plastic characteristics, i.e., to embrittlement.

Today alloy VT8 is the most stable of the alloys intended for long-term work at temperatures up to 500°. In comparison, alloy VT9 has higher heat-resistance characteristics at 500-550°, but its thermal stability is inferior.

The purpose of this study was to search for the composition of

an alloy with heat-resistance properties which are at least as good as those of alloy VT9, but with greater thermal stability.

Alloy type VT3-1, which is alloyed from various elements, was used for the study. The mechanical properties of this alloy were studied at room and raised temperatures (300-600°), as well as its thermal stability in the 400-550° range after holding for 100, 500, 2000, 3000, 6000 and 10,000 hours, its stress-rupture strength at 450, 500 and 500° for 100 hours or more, and its creep at 500° for 100 hours after two modes of heat treatment:

1) heating at 870° for one hour, cooling to 650°C, holding for two hours, cooling in air;

2) heating at 920° for one hour, cooling in air, heating at 590° for one hour, cooling in air.

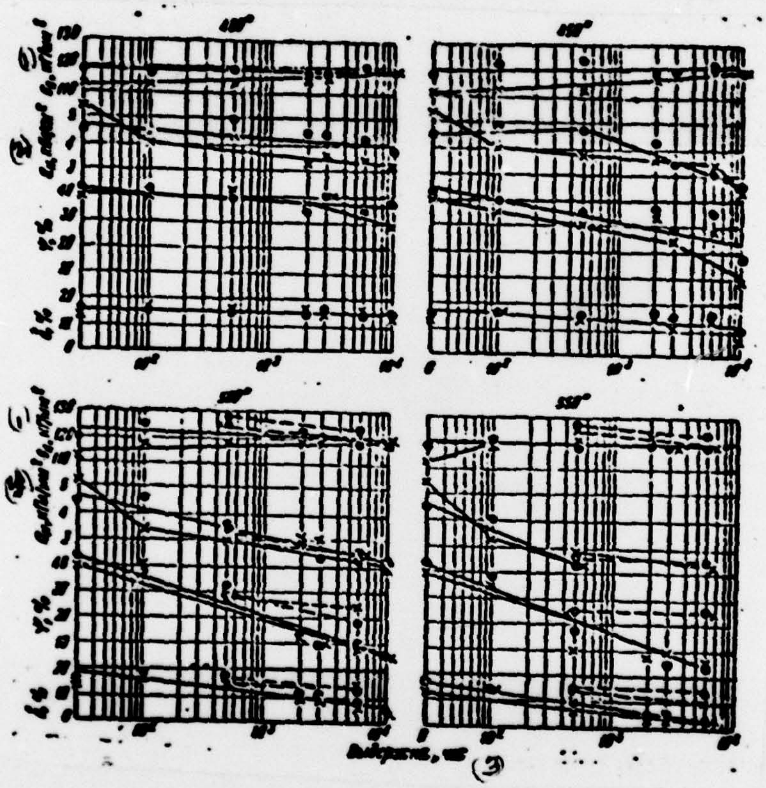
Effect of Prolonged Heating on the Properties of the Alloy

The alloy's thermal stability was studied on Gagarin and Menazh specimens.

The data in the figure show that the alloy has high thermal

stability after both modes of heat treatment and additional holding for up to 10,000 hours at 400 and 450°, while its mechanical properties (σ_b = 110-120 kg/mm²; δ = 10o/o; ψ = 30o/o; a_n = 3 kgm/cm²) are virtually at the level of the original values. After prolonged holding for up to 500 hours at 500°, the high level of mechanical properties is preserved after both modes of heat treatment. Plasticity gradually decreases as the duration of holding increases; however, even after holding for 10,000 hours it remains at an adequate level ($\delta \simeq$ 5-8o/o; $\psi \simeq$ 10-15o/o; a_n = 2-3 kgm/cm²), and embrittlement of the alloy is not observed. At 550°, the mechanical properties of the alloy are only stable after holding for up to 100 hours. Increasing this time to 500 hours leads to a reduction in plasticity, especially transverse constriction of up to 10-17o/o, while after holding for 2000 hours, plasticity remains at the level $\delta \simeq$ 5o/o and $\psi \simeq 10\%$.

Figure. Effect of prolonged holding at different temparatures on mechanical properties of alloy: ● - double annealing; X - isothermic annealing; - - - - annealing of blanks. KEY: (1) kg/mm². (2) kgm/cm². (3) Holding, hours. (4) kgm/mm².



The nature of the change in the alloy's mechanical properties after long-term heating at different temperatures virtually does not depend on heat treatment; the alloy only has lower stress-rupture strength after isothermic annealing.

The data obtained show that the alloy is stable at 450° and holding for up to 10,000 hours, at 500° - up to 1000 hours, and at 550° - up to 100 hours. However, at 500 and 550°, plasticity is maintained at an adequate level after holding for up to 6000 and 3000 hours, respectively ($\delta = 5\%$; $\psi = 10\%$).

The effect of surface oxidation on plastic characteristics after holding for more than 2000 hours at 500° and for 1000 hours at 550° was observed during the comparison of the tests on the blanks and specimens subjected to long-term heating.

The study showed that the alloy has a tendency toward increased thermal stability with the reduction in the temperature of low-temperature annealing. This is obviously due to the high stability of the β-phase; this phase tends to be enriched with β-stabilizing elements to a great extent at a lower temperature. Therefore, in order to provide higher thermal stability of the alloy, it is necessary to anneal it at temperatures close to working temperatures.

Phase Composition of Alloy After Prolonged Heating

The alloy's stability was evaluated by the change in the parameter of the crystalline lattice of the β-phase depending on the time and temperature of heating. It was established that after aging at 400° for from 100 to 3000 hours, the β-phase parameter gradually decreases, indicating its gradual decomposition. The parameter remained virtually the same after heating longer than 3000 hours. After aging at 450, 500 and 550°, a marked decrease even occurs after holding for 100 hours, followed again by an insignificant change in the parameter. The higher the aging temperature, the faster the β-phase decomposes. According to the electrochemical phase analysis data, during prolonged aging this phase is enriched with β-stabilizing elements due to impoverishment and partial decomposition.

By studying the microstructure on an electron microscope, it was established that the structure of the alloy consists of α- and β-solid solutions after isothermic annealing, while after double annealing, there are heterophase sections - products of the decomposition of the metastable β-phase - along with the residual

β-phase. The presence of heterophase sections provides higher strength and and heat-resistance properties of the alloy. According to the preliminary data, crushing and enlargement of the needles in the heterophase sections occur during prolonged holding of specimens for up to 100 hours (at different temperatures), while in the isothermic annealing mode, the form of the phase interfaces changes and serration (after prolonged heating at 450°) or crushing of the plates (after prolonged heating at 500°) occur.

Heat Resistance of Alloy

The study of the heat resistance of the experimental alloy showed that:

1) the tensile strength at raised temperatures (450-600°) virtually does not depend on the heat treatment mode (table);

2) the tensile strength is somewhat higher (85, 70 and 40 kg/mm²) after double annealing than after isothermic annealing (83, 64 and 37 kg/mm²) at all test temperatures (450, 500 and 550°, respectively);

3) the alloy's tensile strength at 500° held for 100 hours (with

residual deformation of 0.2o/o) is equal to 33 kg/mm^2 after isothermic and 40 kg/mm^2 after double annealing.

The table gives the mechanical properties of the experimental alloy compared to the properties of alloys VT8 and VT9.

Table. KEY: (1) Alloy. (2) Test temperature. (3) kg/mm². (4) Thermal stability after heating at 500°. (5) kgm/cm². (5) Experimental. (7) *Duration of holding alloy VT9 - 2030 hours, experimental alloy - 6000 hours.

(1) Сплав	Темпе-ратура испы-тания, °C (2)	$\sigma_в$	σ_{100}	$\sigma_{0,2/100}$	(4) Термическая стабильность после нагрева при 500°*		
		кГ/мм² (3)			δ	ψ	$a_н$ (5) кГм/см²
					%		
ВТ8	20	105—125	—	—	—	—	—
	450	80	75	53	—	—	—
	500	75	55	22	—	—	—
	550	—	38	10	—	—	—
ВТ9	20	105—125	—	—	—	—	—
	450	82	—	—	—	—	—
	500	78	65	40	5	10	1,5
	550	73	40	14	—	—	—
	600	70	23	—	—	—	—
(6) Опытный	20	110—120	—	—	—	—	—
	450	90	85	—	—	—	—
	500	84	70	40	5	10	2
	550	80	40	—	—	—	—
	600	75	—	—	—	—	—

(7) * Длительность выдержки сплава ВТ9 2000 час, опытного сплава — 6000 час.

The analysis of the data obtained shows that the heat resistance and creep of the experimental alloy are at the same level as these characteristics of alloy VT9, while its thermal stability considerably exceeds that of VT9 at 500°. The use of the new titanium alloy makes it possible to increase the service life of articles at 500° from 500 to 5000 hours.

Conclusions

1. A composition of the alloy which provides reliable operation at temperatures up to 500° and a holding time of up to 10,000 hours, and at 550° - of up to 3000 hours - was obtained (versus 2000 and 100 hours for alloy VT9). The heat resistance of the experimental alloy is on the level of that of alloy VT9.

2. The effect of heat treatment and long-term heating for up to 10,000 hours at 400, 450, 500 and 550° on the properties, structure and phase composition of a complex-alloyed titanium alloy was studied. A tendency toward an increase in the thermal stability of the alloy with the decrease in the temperature of low-temperature annealing connected with the high stability of the β-phase was detected.

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